[0044] Piezoelectric and electrostrictive materials develop a polarized electric field when placed under stress or strain. Conversely, they undergo dimensional changes in an applied electric field. The dimensional change (i.e., expansion or contraction) of a piezoelectric or electrostrictive material is a function of the applied electric field. Piezoelectric and electrostrictive materials can possess a large number of combined and useful properties such as piezoelectric (electric field dependent strain), electrostrictive, dielectric, pyroelectric (temperature dependent polarization), ferroelectric (electric field dependent polarization) and electrooptic (electric field dependent optical birefringence). These devices have a wide range of applications which include actuators, sensors, switches, benders, accelerometers, and strain gauges.

[0045] Under an applied electric field, a piezoelectric crystal deforms along all its axes. It expands in some directions and contracts in others. The piezoelectric or strain coefficient describing this deformation is commonly denoted by the tensor d_{ij}:

$$d_{ij}=X/E_i(\text{constant } X)=P_i/X_j(\text{constant } E)$$

[0046] where x equals strain (extension per unit length); X equals stress (force per unit area); E equals electric field (volts per meter), and P equals polarization (Coulombs per square meter). The subscripts i,j refer to the crystal axes, or in the case of ceramics, to the direction of polarization of the ceramic. For example, d_{31} is the strain coefficient in the lateral direction while d_{33} is the strain coefficient for the longitudinal direction.

[0047] A typical device such as a direct mode transducer makes direct use of a change in the dimensions of the material, when activated, without amplification of the actual displacement. The direct-mode actuator typically includes a piezoelectric or electrostrictive plate sandwiched between a pair of electrodes formed on its major surfaces or embedded within the material. The device is generally formed of a material which has a sufficiently large piezoelectric and/or electrostrictive coefficient to produce the desired strain in the plate. Applying a voltage of appropriate amplitude and polarity between some dimensions of the device, it will cause the piezoelectric (or electrostrictive) material to contract or expand in that direction. On the other hand, applying a load to extend or compress a piezoelectric transducer causes the voltage at the electrodes to vary. When the device expands or contracts in one dimension (the thickness or longitudinal direction) it generally contracts or expands respectively, in dimensions in a plane perpendicular thereto (planar or transverse directions). A piezoelectric or other force-to-signal transducing element can be utilized in the sensing transducers **128**, **130**, **132**, **134** to produce a signal to the microcontroller **98** relating the tension in a binding of one of the attaching elements **90**, **92**, **94**, and **96** and any change in tension produced by changes in the size and density of the muscles, or relative movement of the limb and bracing element **84**.

[0048] The tension in one of the bindings of the attaching elements **90**, **92**, **94**, and **96** of the brace **80** can be varied in response to a signal output by the controller **98** to one of the drivers. Referring again to **FIG. 4**, a loading transducer **156** comprising plurality of electroactive polymer tensioning elements **172** is utilized to alter the length of the binding **152** and, as a consequence, the force exerted by the attaching element **150**. Electroactive polymers deflect when actuated by electrical energy. To help illustrate the performance of an electroactive polymer in converting electrical energy to mechanical energy, **FIG. 5A** illustrates a top perspective view of a transducer portion **200** comprising an electroactive polymer **202** for converting electrical energy to mechanical energy or vice versa. An electroactive polymer refers to a polymer that acts as an insulating dielectric between two electrodes and deflects upon application of a voltage difference between the two electrodes. Top and bottom electrodes **204** and **206** are attached to the electroactive polymer **202** on its top and bottom surfaces, respectively, to provide a voltage difference across a portion of the polymer. The polymer **202** deflects with a change in electric field provided by the top and bottom electrodes **204** and **206**. Deflection of the transducer portion **202** in response to a change in the electric field is referred to as actuation. As the polymer **202** changes in size, the deflection may be used to produce mechanical work. In general, deflection refers to any displacement, expansion, contraction, torsion, linear or area strain, or any other deformation of a portion of the polymer. The change in the electric field corresponding to the voltage difference applied to or by the electrodes **204** and **206** produces mechanical pressure within the polymer **202**. As illustrated by comparing the length **212**, width **210**, and depth **208** dimensions of **FIGS. 5A and 5B** electroactive polymer transducers deflect in all dimensions simultaneously. In general, the transducer portion **200** continues to deflect until mechanical forces balance the electrostatic forces driving the deflection. The mechanical forces include elastic restoring forces of the polymer material, the compliance of the electrodes **204** and **206**, and any external resistance provided by a device or load coupled to the transducer element.

[0049] Electroactive polymers and electroactive polymer transducers are not limited to any particular shape, geometry, or type of deflection. For example, a polymer and associated electrodes may be formed into any geometry or shape including tubes and rolls, stretched polymers attached between multiple rigid structures, and stretched polymers attached across a frame of any geometry, including curved or complex geometries; or a frame having one or more joints. Deflection of electroactive polymer transducers includes linear expansion and compression in one or more directions, bending, and axial deflection when the polymer is rolled.

[0050] Materials suitable for use as an electroactive polymer may include any substantially insulating polymer or rubber (or combination thereof) that deforms in response to an electrostatic force or whose deformation results in a change in electric field. One suitable material is NuSil CF19-2186 as provided by NuSil Technology of Carpenteria, Calif. Other exemplary materials include silicone elastomers such as those provided by Dow Corning of Midland, Mich., acrylic elastomers such as VHB 4910 acrylic elastomer as produced by 3M Corporation of St. Paul, Minn., polyurethanes, thermoplastic elastomers, copolymers comprising PVDF, pressure-sensitive adhesives, fluoroelastomers, polymers comprising silicone and acrylic moieties, and the like. Polymers comprising silicone and acrylic moieties may include copolymers comprising silicone and acrylic moieties, polymer blends comprising a silicone elastomer and an acrylic elastomer, for example. Combinations